EUVL Symposium 2012

EUVL mask repair: expanding options with nanomachining

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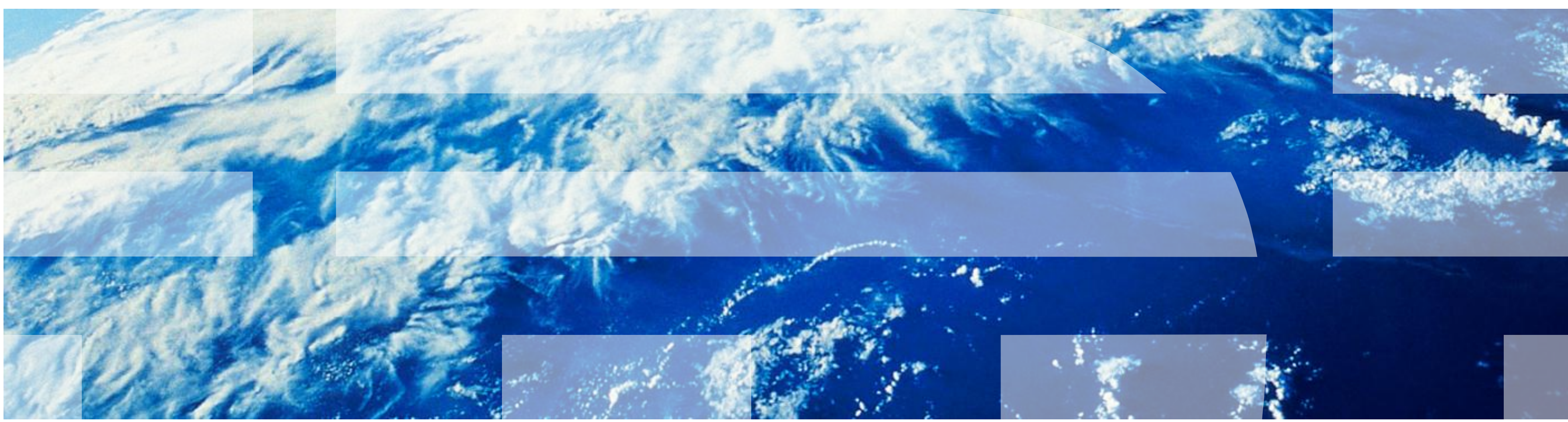


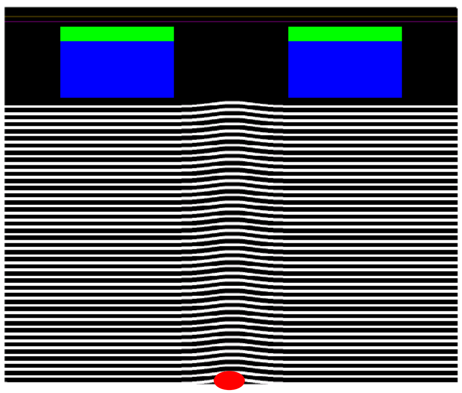
Outline

Purpose: Introduce method to repair both the phase and amplitude effects of a multi-layer bump defect

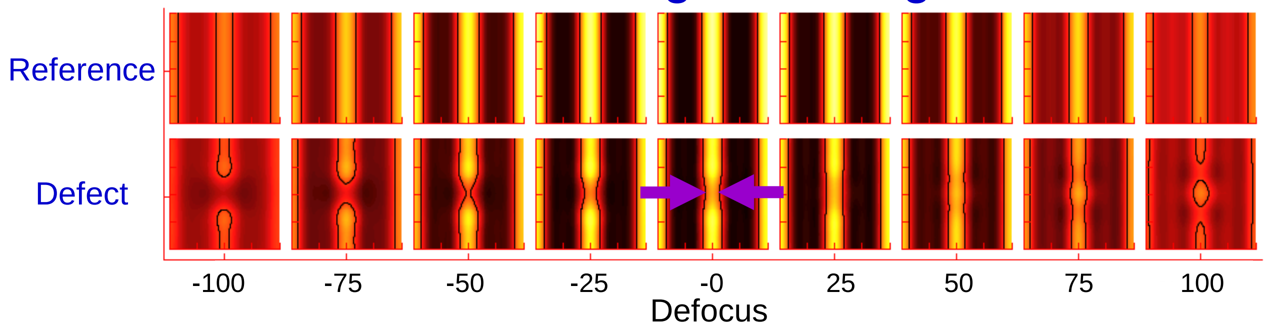
- Multi-layer (ML) defect review
  – Review of mitigation/compensation strategies
- Phase repair
- AFM – options for nanomachining defects
- Experimental results
  – Clear area repairs
  – Line-space repairs
- Putting it all together: ML defect repair with AFM
- Conclusions

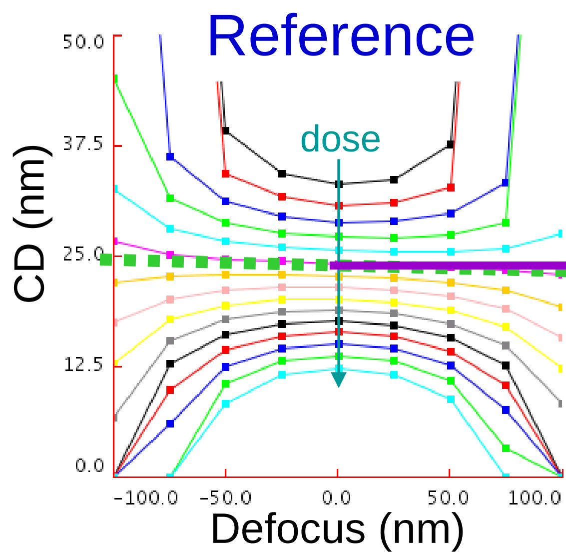
Multilayer bump defect

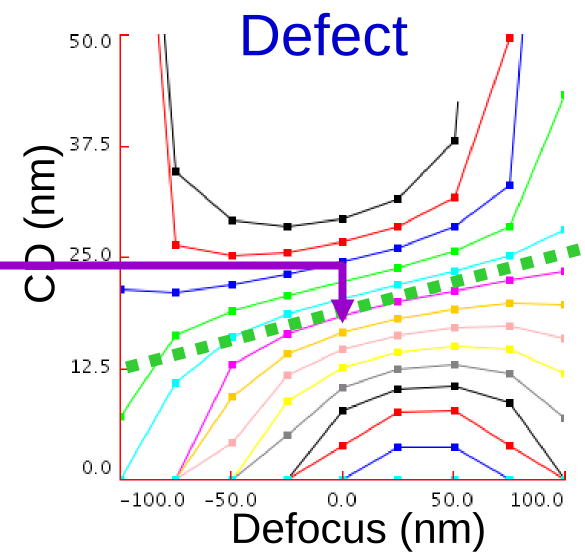
- Multilayer defects are unlikely to be eliminated completely from blanks
- ML defects create both phase and amplitude effects


Substrate defect

Simulated Images Through Focus





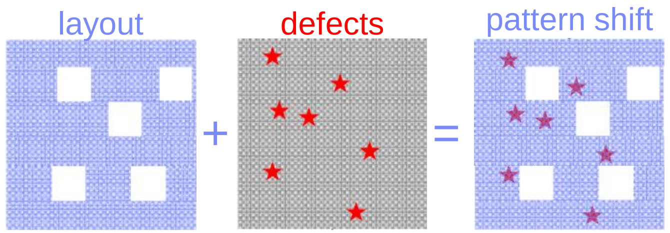


Bossung Tilt = Phase effect

CD error = Amplitude effect

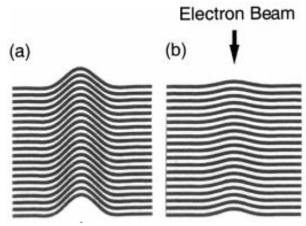
Strategies for mitigating impact of ML defects

- Pattern shift



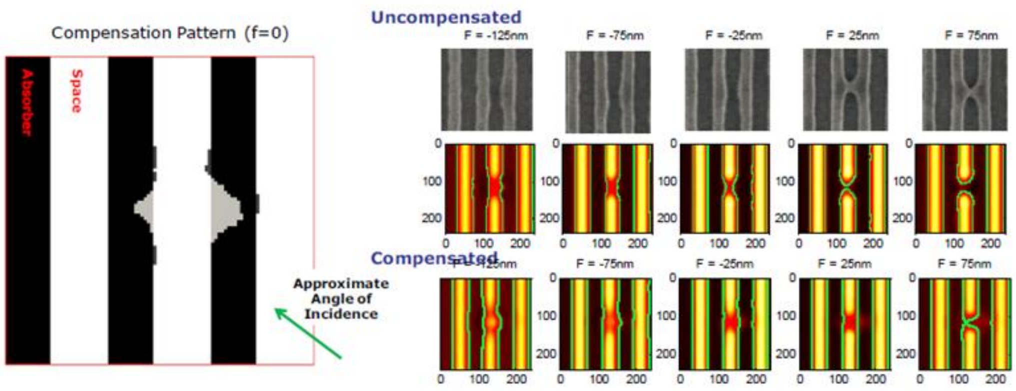
E. Gallagher, et al., EUVL Symposium 2011.

- Repair defects before absorber deposition



P. B. Mirkarimi et al., J. Appl. Phys. 91, 81 (2002).

- Absorber compensation



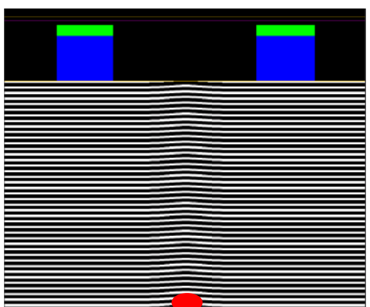
L. Pang et al., Proc. of SPIE Vol. 8166, 2011.

- **Phase repair + absorber compensation**

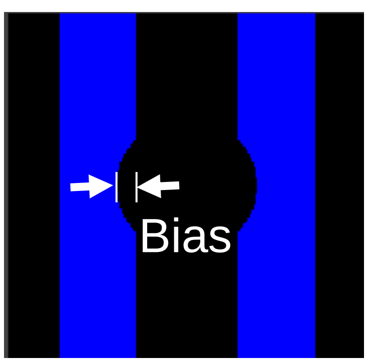
(Topic of this presentation)

Absorber-only compensation example

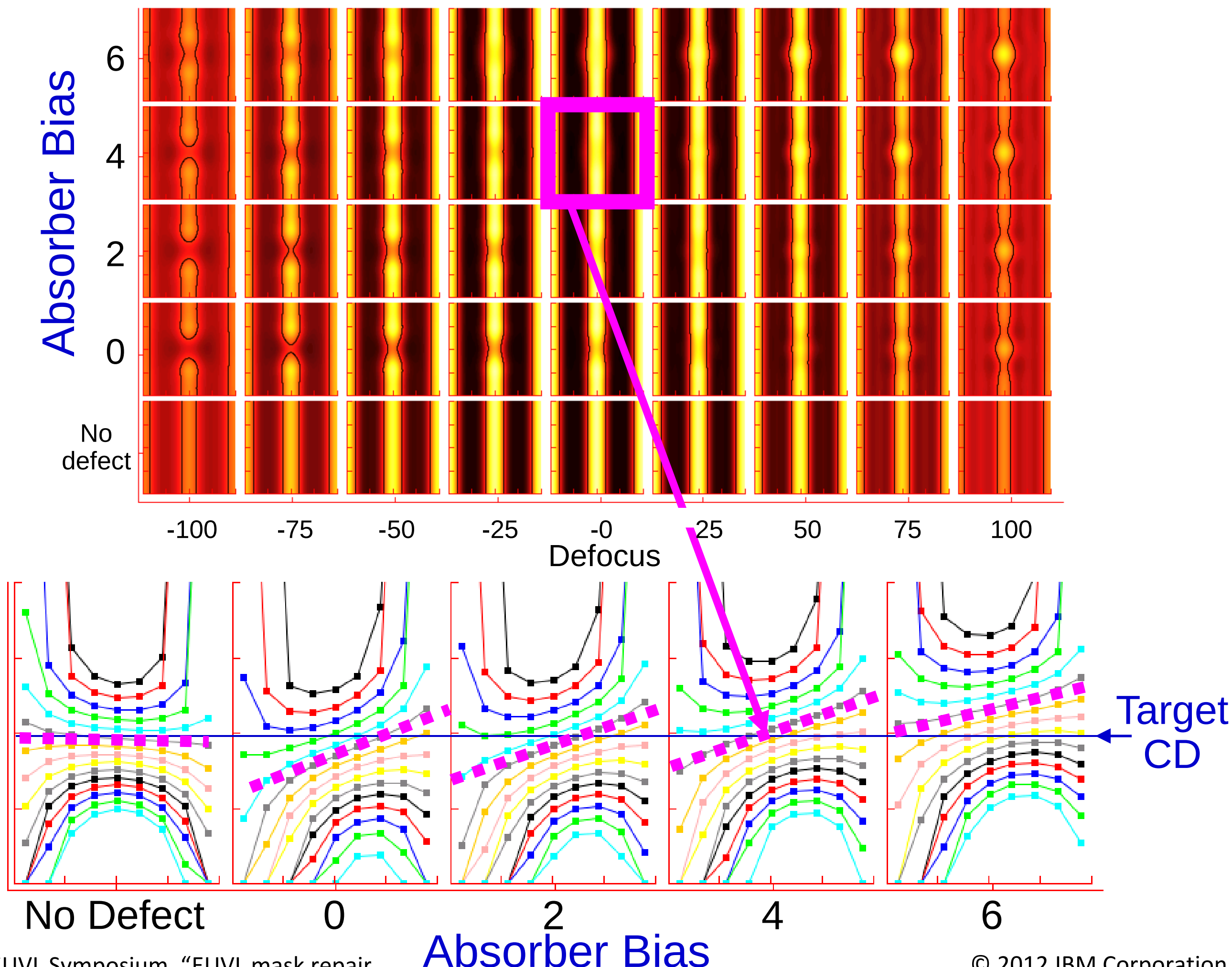
- 28nm HP, ML defect with 2nm bump height (47nm FWHM) centered in space
- Simple absorber bias compensates amplitude effect
- Little impact on phase effect (asymmetric behavior through focus remains)



Side view



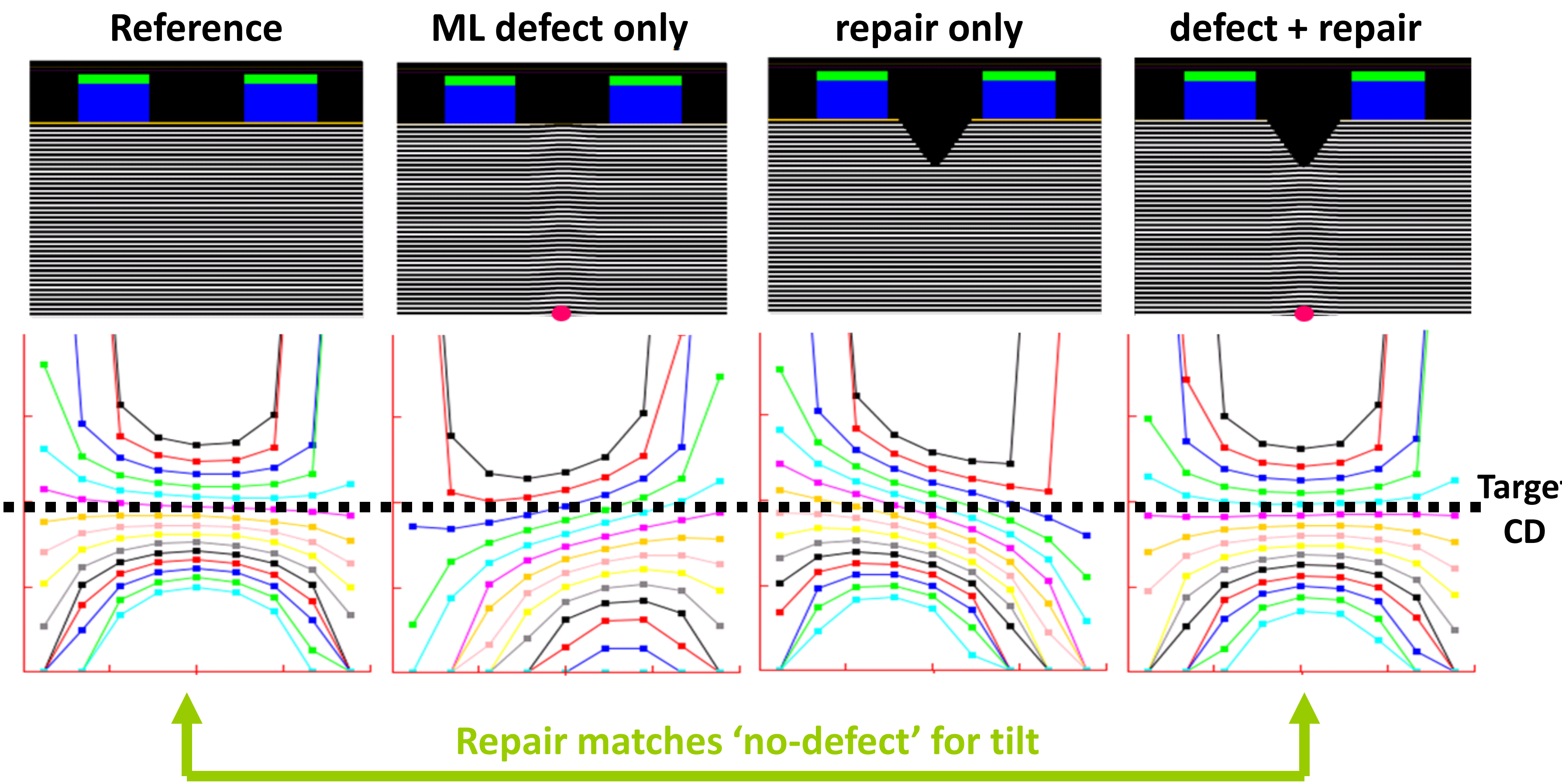
Top-down



G. McIntyre, 2012 EUVL Symposium, “EUVL mask repair

Phase compensation with ML repair

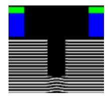
- Creation of pit at top of ML to counteract phase effect of bump defect
- Bossung tilt is corrected; absorber bias still required

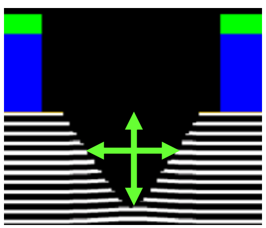


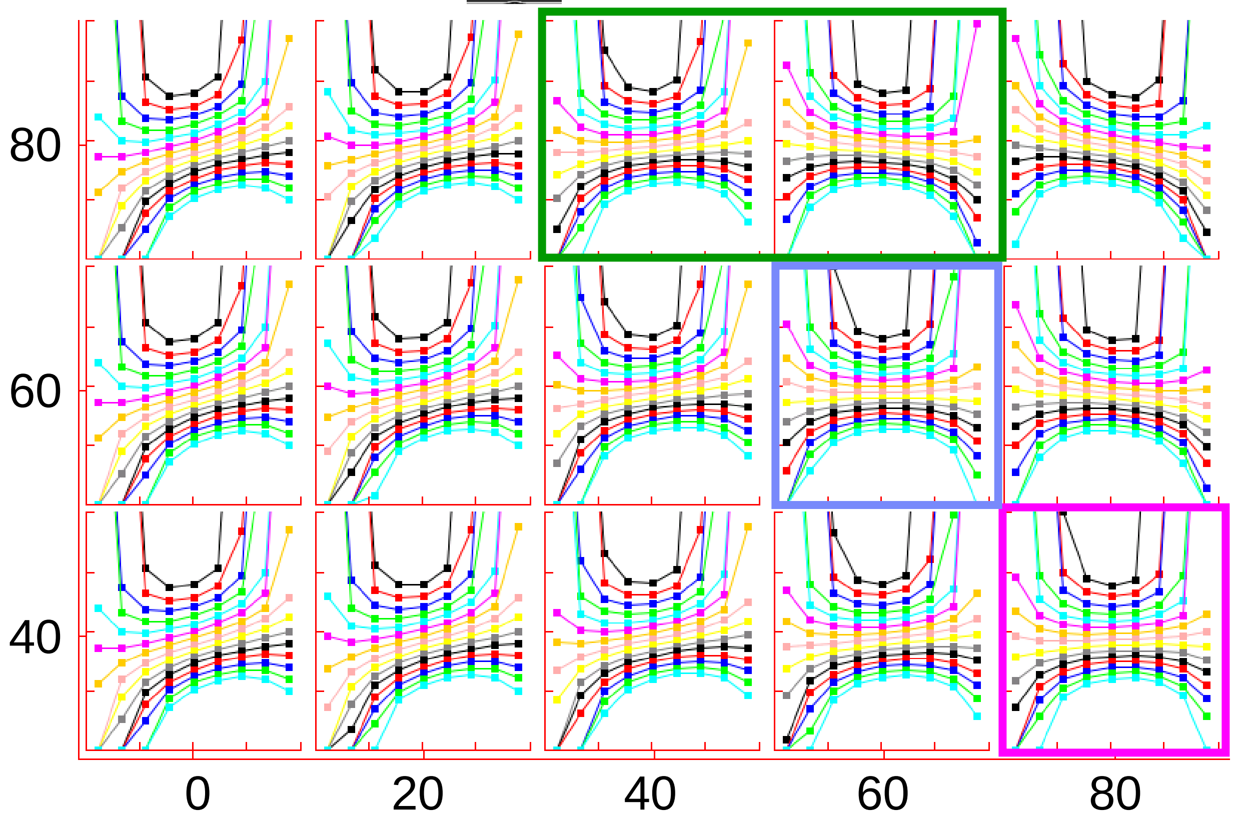
Small CD shift is still needed

G. McIntyre, 2012 EUVL Symposium, “EUVL mask repair: expanding options with nanomachining”

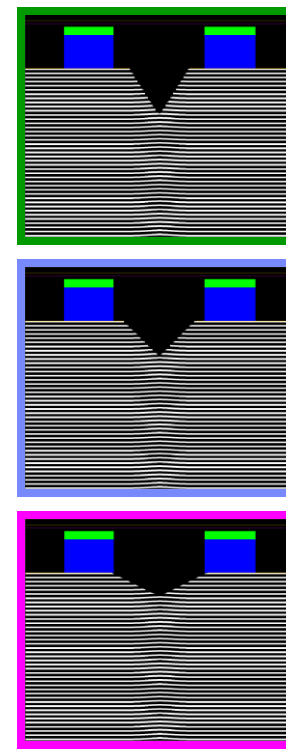
Phase compensation with ML repair

- Vary repair dimensions (28nm HP example with 2nm bump height & 47nm FWHM)
- Multiple combinations of width and depth can be selected
  - Depth is 30-90nm (depending on ML bump defect height)
  - Width is roughly FWHM of ML defect
- Other shapes can be used (i.e. )



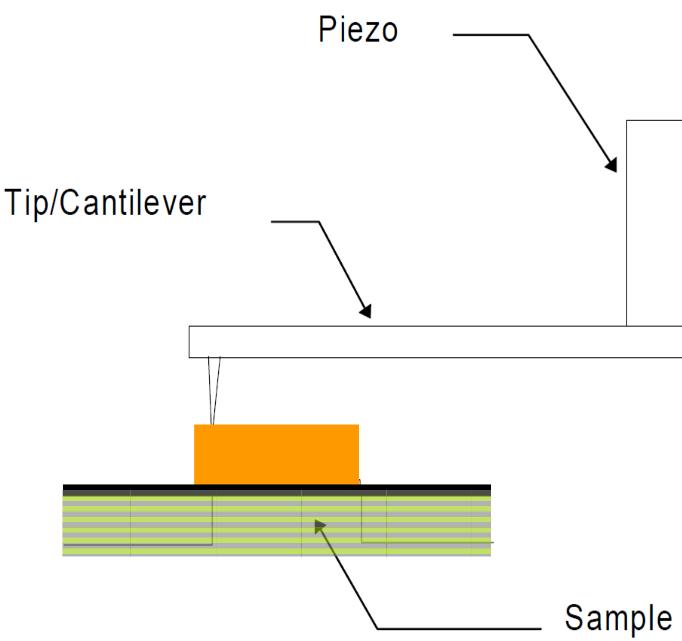


Repair Width (nm, 4x)



Nanomaching process

- Merlin® nanomachining removes material without etch stops, heat or gases in 3 steps
  - Step 1: non-contact AFM scan of defect and reference structures to the nanometer level
  - Step 2: contact mode removes material using cold mechanical processes (NanoBit®)
  - Step 3: particulate debris is removed using EcoSnow, BitClean®, wet cleaning, etc.



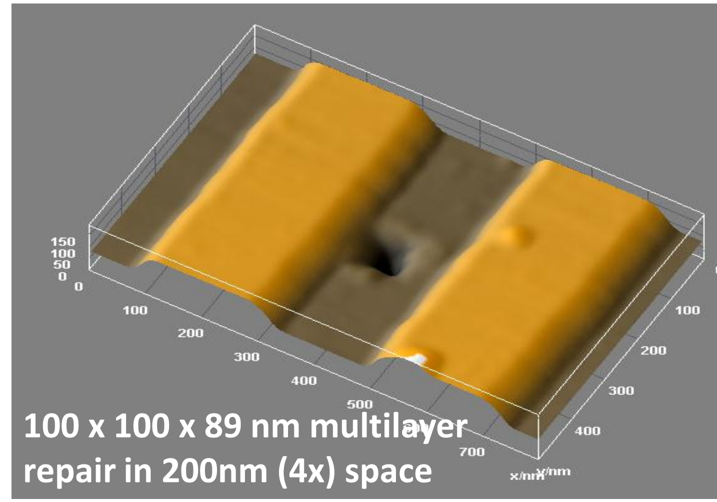
G. McIntyre, 2012 EUVL Symposium, “EUVL mask repair: expanding options with nanomachining”

Options for nanomaching defects

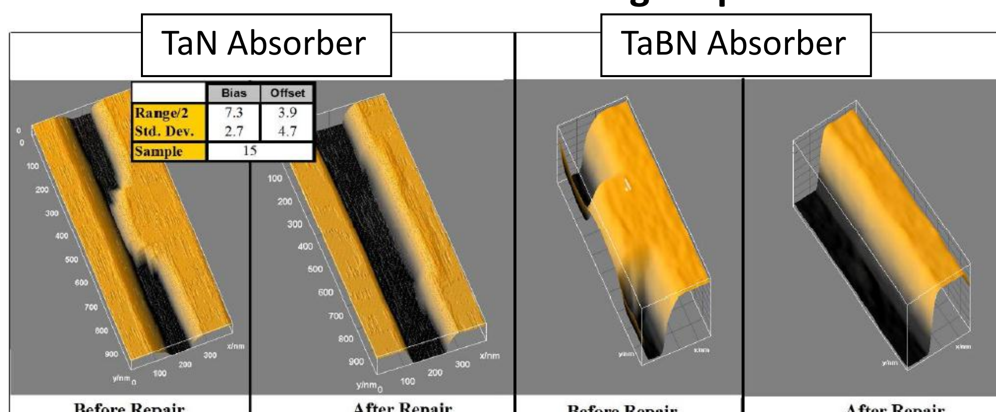
- Multilayer material removal
  - Remove multilayer material to precise depths and widths to create a phase change

- Opaque removal
  - Remove extra material to restore design
  - Compensate for amplitude effect of defect and phase repair

Multilayer material removal



Ta-based absorber edge repair



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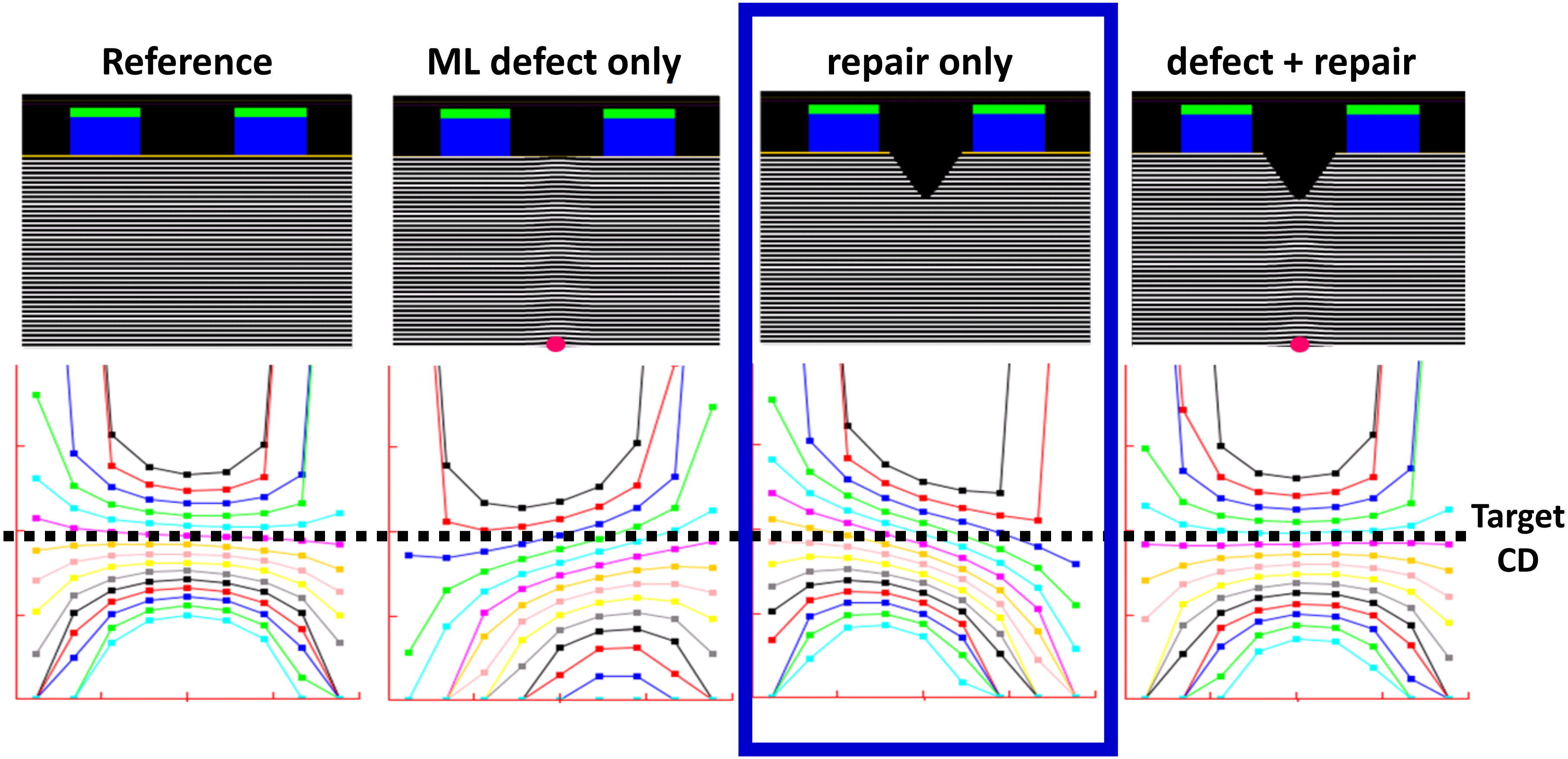
IBM

Experimental Work

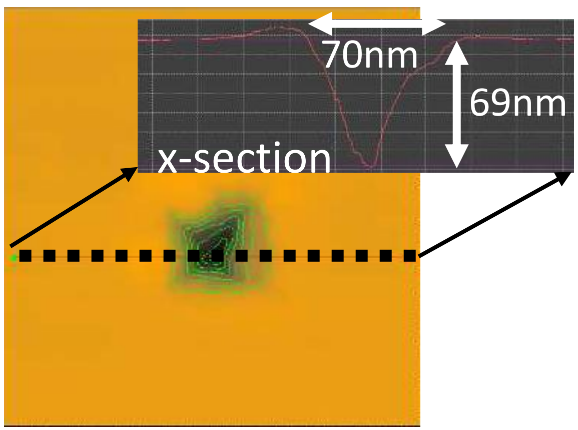
- Goal of initial experimental work is to verify "repair-only" behaves as predicted by simulation
- Good match suggests feasibility to determine required repair via modeling



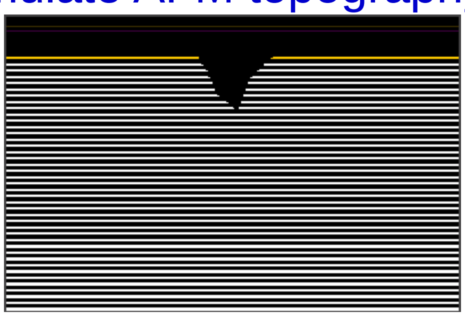
Experimental results: clear area “repair” example

- Nanomachined a 70nm square, ~69nm deep “repair” on an EUVL mask multilayer surface
- Imaged on Actinic Inspection Tool (AIT) – EUV microscope
  - Phase response through focus similar to simulation of AFM topography
  - Some amplitude offset observed

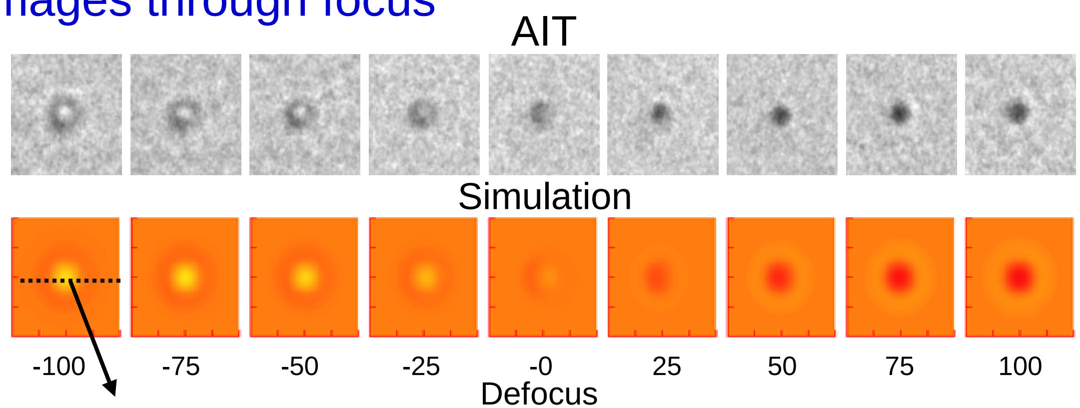
AFM Scan



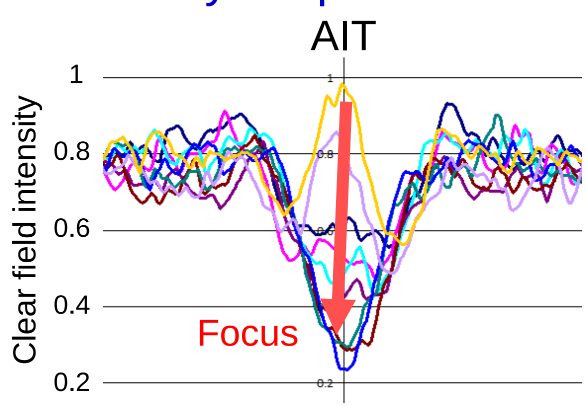
Simulate AFM topography

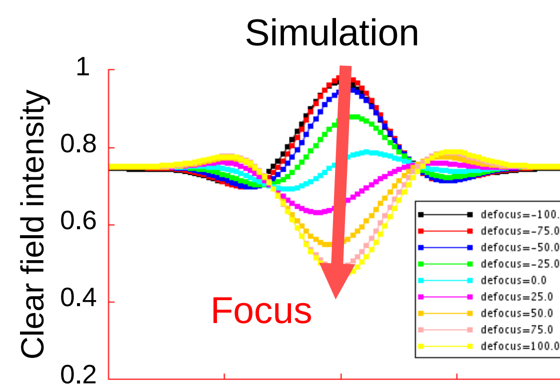


Images through focus



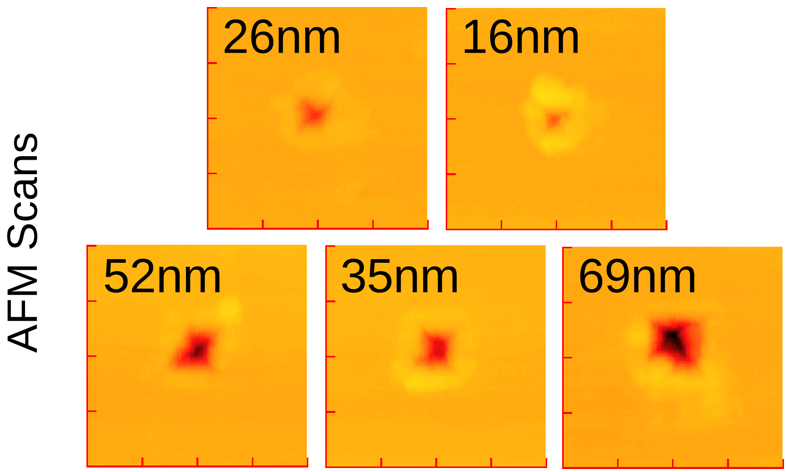
Intensity vs. position

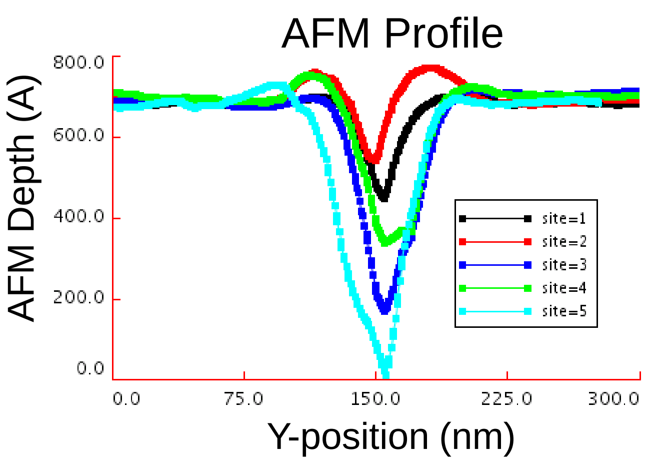




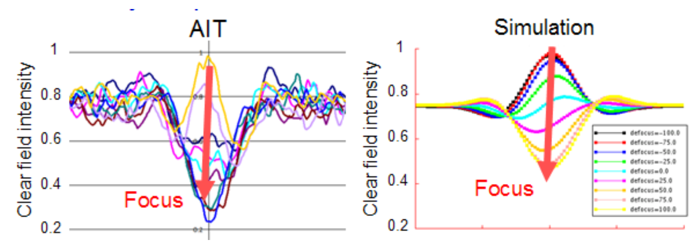
Experimental results: clear area “repair” example

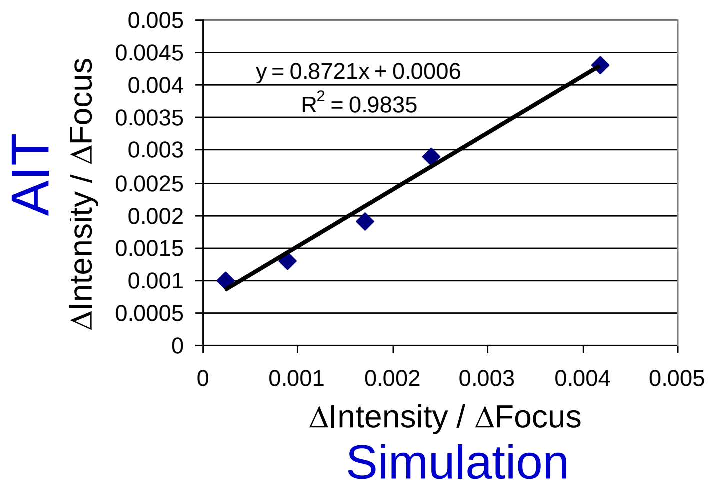
- Analysis of 5 repair sizes (depth varies between 16 and 69 nm)
- Strength of phase response (ΔIntensity / ΔFocus) similar to simulation of AFM topography
- Good match suggests ability to determine required ML defect repair with simulation





Phase response = ΔIntensity / ΔFocus

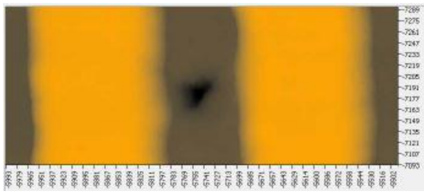




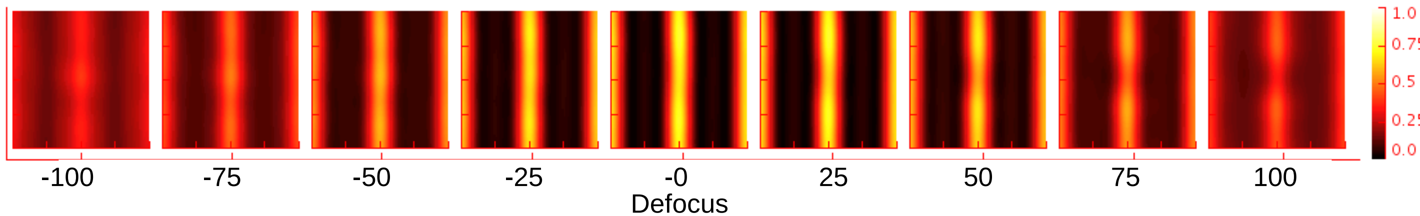
Experimental results: 32nm HP line-space "repairs"

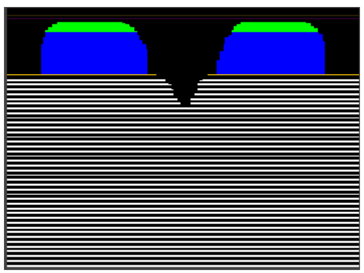
- Simulation of AFM topography predicts Bossung tilt

AFM (50nm deep "repair")

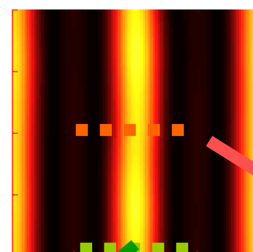


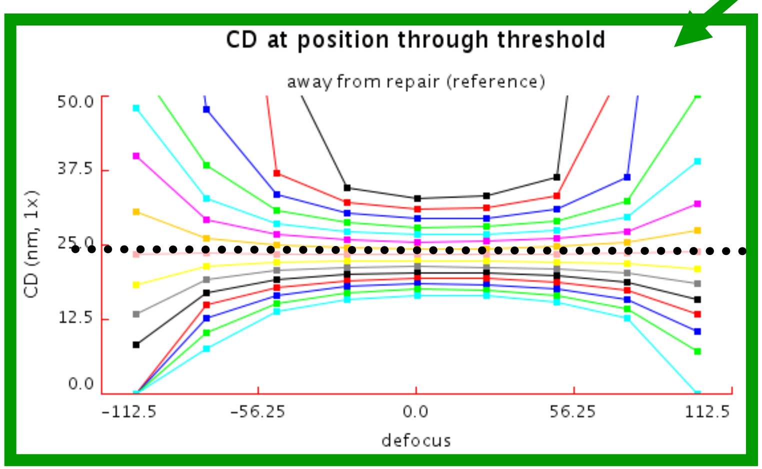
Through focus response of multilayer "repair"

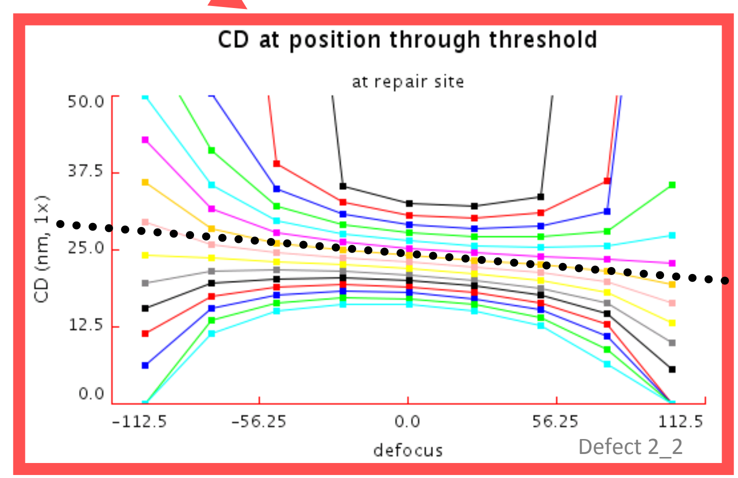




Simulation of AFM topography



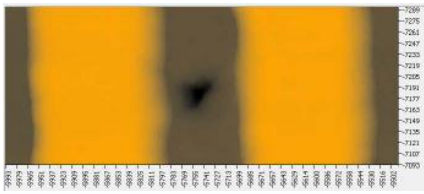




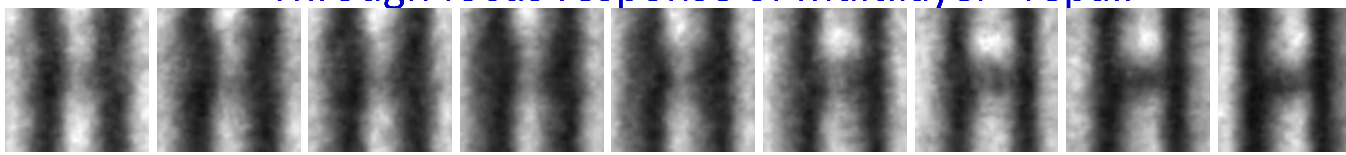
Experimental results: 32nm HP line-space “repairs”

- AIT Imaging results closely match tilt predicted by simulation

AFM (50nm deep “repair”)



Through focus response of multilayer “repair”



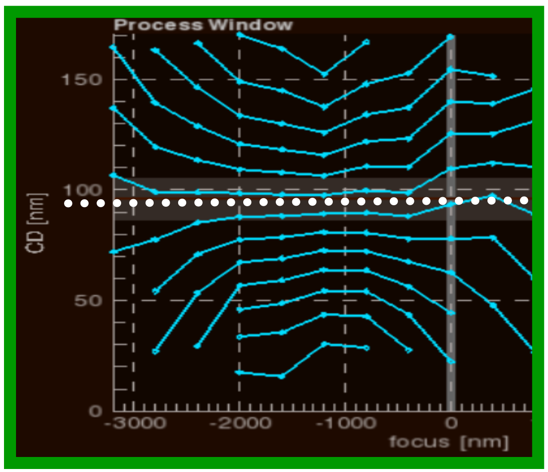
-100 -75 -50 -25 -0 25 50 75 100

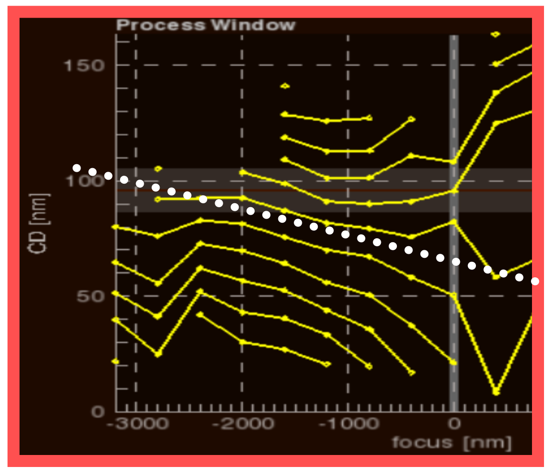
Defocus

Reference

“repair”

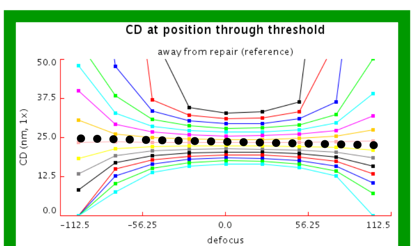
AIT

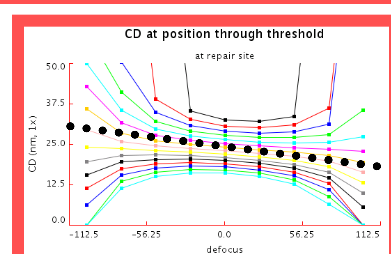




- Iso-focal Bossung slopes both very close to 4nm ΔCD in ±50nm defocus

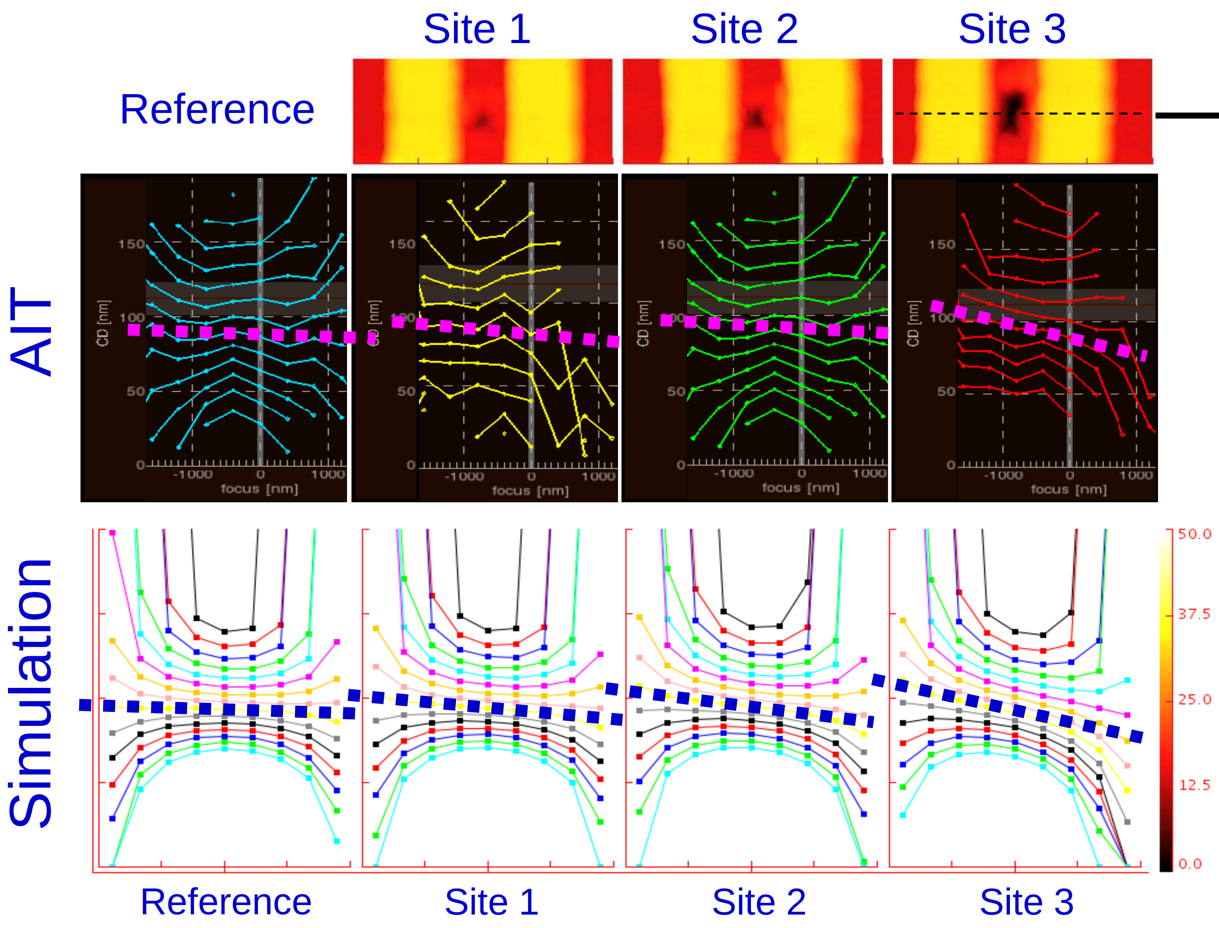
Simulation

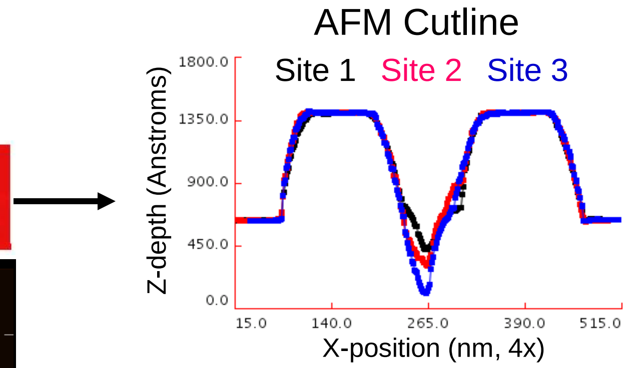


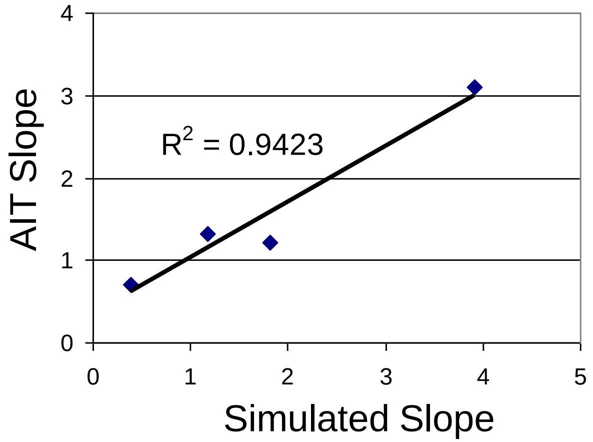


Experimental results: 28nm HP "repairs"

- 3 Sites of varying "repair" depth analyzed (32, 48 & 70nm deep)
- AIT data confirms expected tilt of Bossungs
- Reasonable match to simulation of AFM topography





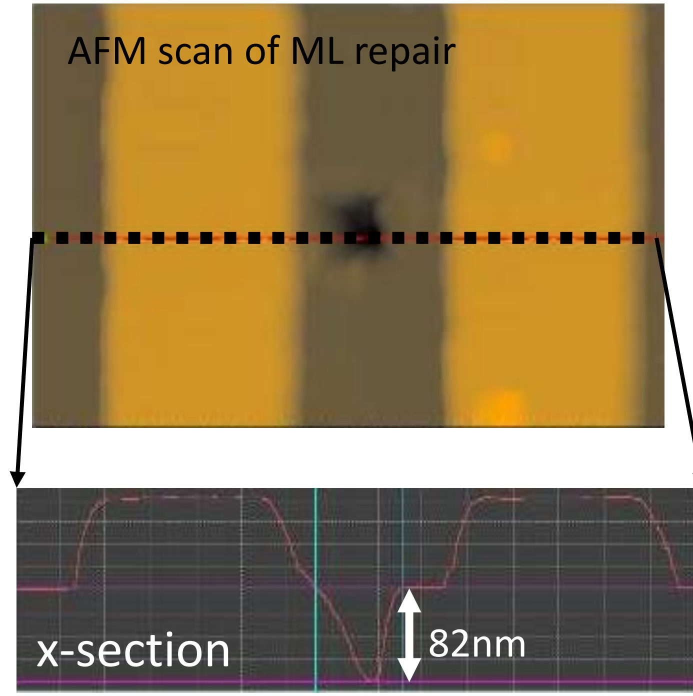


Slope = ΔCD in ±50nm defocus

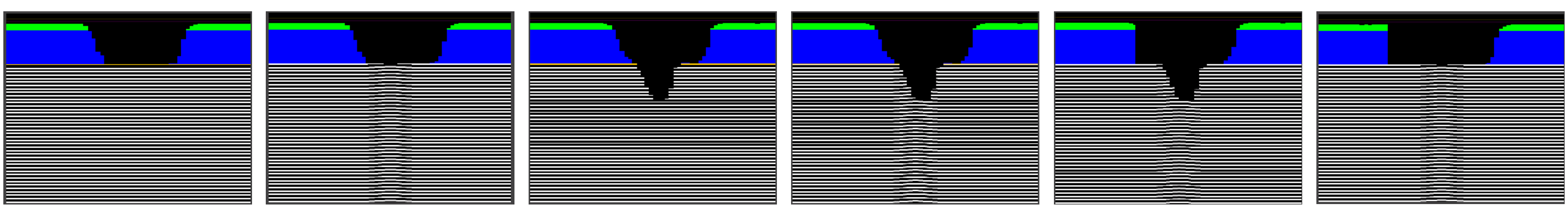
Putting it all together: ML defect repair

- Repair process
  - Characterize defect (imaging, AFM)
  - Model defect
  - Model required repair dimensions
  - Repair phase + absorber compensation
  - Verify & fine tune

- Example of real mask repair with simulated defect:
  - 82nm deep "repair" & BitClean®
  - 50nm HP lines (note: successful nanomachining demonstrated down to 22nm HP lines)
  - Place repair over simulated off-center defect

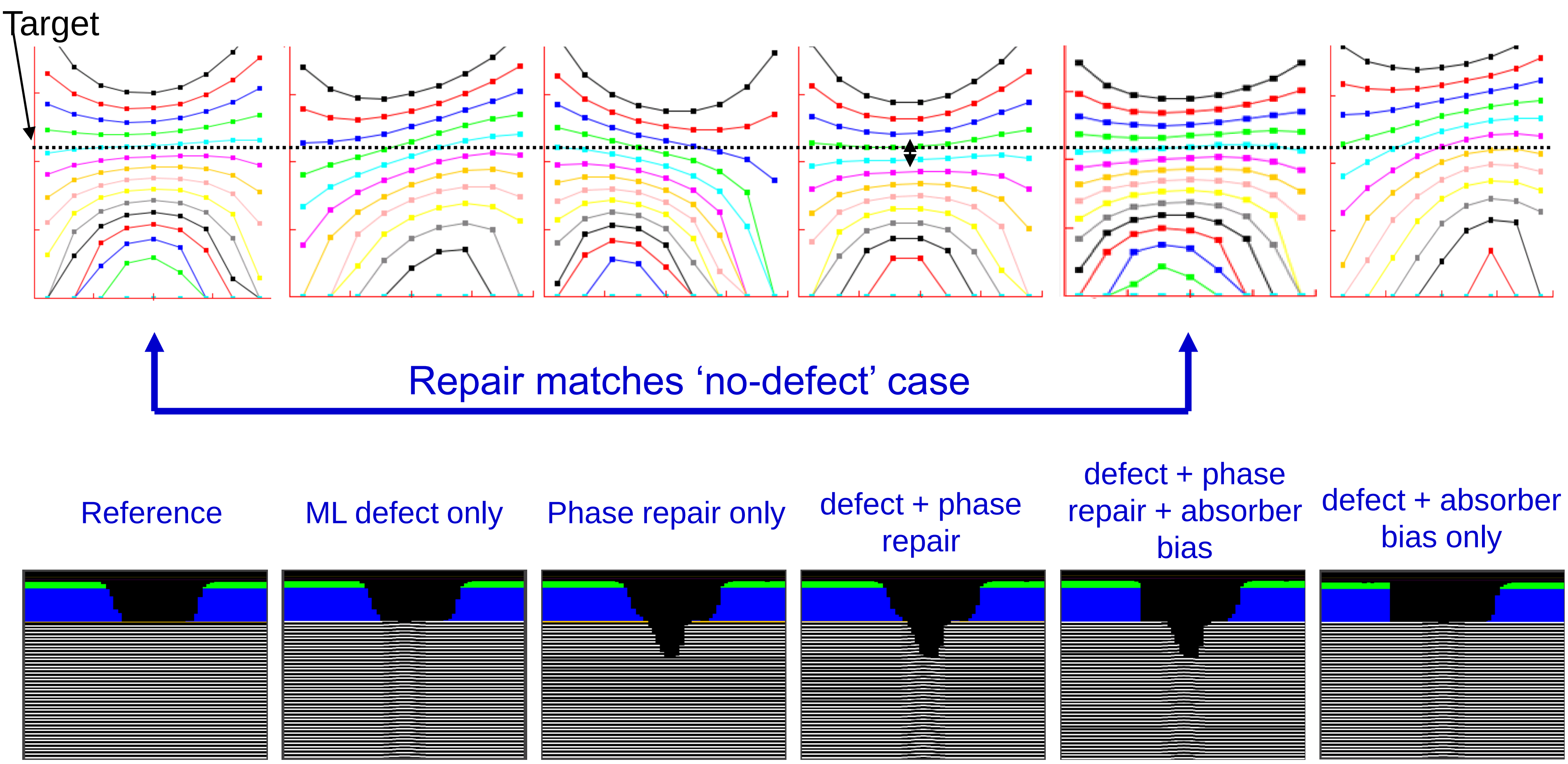


Reference | ML defect only | Phase repair only | defect + phase repair | defect + phase repair + absorber bias | defect + absorber bias only



Putting it all together: ML defect repair

- Phase repair restores the Bossung tilt
- Absorber repair restores target print CD

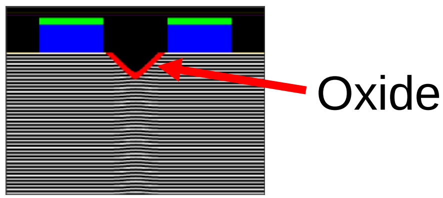


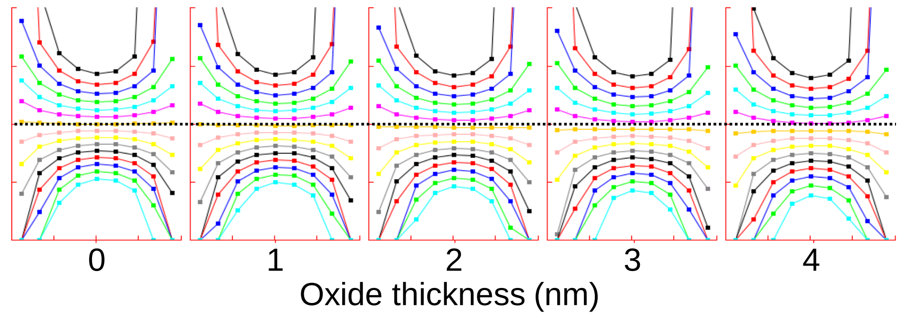
Summary

- Multilayer defects have both amplitude and phase effects
  - A complete multilayer repair addresses both
- Nanomachining provides new ML defect repair capabilities
  - Multilayer to adjust phase
  - Absorber to change amplitude
- Achieved good agreement between simulation and AIT data
  - Isolated pits created in clear multilayer
  - Line/space patterns in geometries down to 28nm HP
- This is a proof of concept. Various areas to be investigated prior to manufacturing implementation

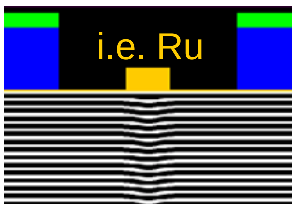
Future work

- Lifetime and durability at repair site needs to be addressed
  - Simulation suggests thin passivation layer would not harm optical effect of repair





- This work focused on bump defects. Similar effect can be achieved for pit defects by depositing material (i.e. bossungs tilted the other way)



Pit defect

- In process of testing concept on ML defect test mask
- Repair specifications and tolerances to be determined
  - Experimental repair work suggests nanomachining can meet specifications
  - Simulation suggests reasonable tolerances
- Reasonable speed and accuracy of computational models required for manufacturing implementation
- AIMS tool could be required for practical implementation

Acknowledgments

- IBM’s mask house engineering and manufacturing teams for mask builds and processing
- Sematech for Actinic Inspection Tool (AIT) time
- Kenneth Goldberg (CXRO), Iacopo Mochi (CXRO), for AIT support and insight